The opinion in support of the decision being entered today was *not* written for publication and is *not* binding precedent of the Board

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE BOARD OF PATENT APPEALS
AND INTERFERENCES

Ex parte TOSHIAKI OHMORI

Appeal 2005-2100
Application 09/826,038
Technology Center 1700

Decided: September 15, 2006

Before ADAMS, JEFFREY T. SMITH, and FRANKLIN, *Administrative Patent Judges*.

FRANKLIN, *Administrative Patent Judge*.

DECISION ON APPEAL

This is a decision on an appeal under 35 U.S.C. § 134 from the examiner's final rejection of claim 6. Claim 6 is reproduced below:

6. A method of manufacturing a semiconductor device including a plurality of processing processes, the method comprising the steps of:

dry etching a predetermined film to be processed;

wet etching, after said step of dry etching, the predetermined film to be processed;

acquiring, after said step of dry etching, the dimension of the film to be processed;

determining processing requirements for said step of wet etching on the basis of the dimension of the film to be processed; and

wherein said step of wet etching is performed in accordance with the processing requirements.

The Examiner relies upon the following reference as evidence of unpatentability:

Funk	US 6,148,239	Nov. 14, 2000

Claim 6 stands rejected under 35 U.S.C. § 103(a) as being obvious over Funk.

OPINION

I. The Art Rejection

The Examiner's position for this rejection is set forth on page 3 of the Answer.

Beginning on page 4 of the Brief, Appellant asserts that Funk fails to teach the following claimed features:

(a) the specific set of processing steps (i.e., dry etching and wet etching);

(b) the specific order in which these processing steps are to be performed (i.e., wet etching after dry etching); and

(c) the specific variable (i.e., dimension of the film) that is to be acquired after the dry etching and later used to determine processing requirements of the wet etching.

On page 5 of the Brief, Appellant also argues that Funk fails to use both wet etching and dry etching in a single set of processing steps, and that the wet etching takes place after dry etching.

In the paragraph bridging pages 5 and 6 of the Brief, Appellant argues that the Examiner has failed to establish a realistic motivation to modify Funk so as to arrive at the claimed limitation of performing wet etching after dry etching. Appellant argues that the Examiner's assertion that "it would have been obvious to one with ordinary skill in the art to perform various processes in various sequences depending on the specific product requirement" is overly broad and based on generalities. Brief, page 6.

Appellant also states that the specific claimed variable that is to be acquired after the dry etching and later used to determine processing requirements of the wet etching is the dimension of the film. Brief, page 7. Appellant states that he is unable to determine whether the FICD measurement disclosed at column 5, lines 36 through 37 of Funk corresponds to the claimed dimension of the film. Brief, page 7.

We are unpersuaded by Appellant's arguments for the following reasons.

We begin first with Appellant's specification which indicates that the crux of their invention is the ability of reflecting the state of a wafer in the requirements for processing the wafer through use of the feedforward technique (Specification, p. 2, ll. 10-14). The method includes a first step of acquiring a measurement value pertaining to a wafer to be subjected to a predetermined processing process. The method also includes a second step of determining processing requirements for the predetermined processing process on the basis of the measurement value. The method further includes a third step of performing the predetermined processing process in accordance with the processing requirements determined in the second step (Specification, p. 2, ll. 20-29).

We first note that on page 1 of Appellant's specification, Appellant admits that it has been known to measure the thickness of a film before and after etching steps of the film in an effort to stabilize processing (Specification, p. 1, ll. 10-29). The measurement is used to feed back a measurement result to etching requirements.

Appellant's specification describes several embodiments as examples of the use of the feedforward technique. Embodiment 1 is described in detail on pages 7-9 of the Specification, and illustrated in Figs 2A and Fig. 2B. An example is described of a typical semiconductor process that involves controlling the step difference between the surface of an isolation oxide film to be embedded in a trench and the surface of a silicon substrate, during the course of manufacture of an element isolation structure through use of a trench structure.

As depicted in Fig. 2A, the silicon substrate 31 is subjected to dry etching, using silicon nitride film 32 as a mask, to form a trench structure. Thereafter, the oxide film 35 is removed by CMP (chemical-and-mechanical polishing), followed by several steps of etching. It is stated that during the course of CMP, errors are likely to occur, making it difficult to accurately form a step difference (Specification, p. 7, ll. 28-33, p.8, ll. 1-19).

As shown in Fig. 2B, according to Appellant's first embodiment, after the above-described CMP processing, the thickness of the oxide film 33 is measured. The resultant measurement value is reflected in the requirements for etching the oxide film 33, by means of the feedforward technique. The oxide film 33 is etched according to the optimal requirement (Specification, page 8, ll. 20-33 and p. 9, ll. 1-10). In this way, a step difference can be accurately controlled (Specification, p. 9, ll. 11-10).

Each of the other embodiments also involves the use of the feed forward technique by measuring the thickness of a film, and the measured thickness value is then transmitted to the main computer which is used to set optimal requirements for future processing. In this way, variations in thickness of a film can be reflected in the requirements for processing (e.g., etching) thereafter. The common benefit is each embodiment resulting from the use of this feed forward technique is improved uniformity/accuracy of the resultant formation during processing.

Our dissenting colleague focuses on embodiment 5 of Appellant's specification because it is this embodiment that supports the subject matter of claim 6. This embodiment is depicted in Figs. 7A- 7E of the drawings. This embodiment involves the processing technique of the formation of a miniaturized interconnection pattern. Appellant uses the feed forward technique to this technique for improved accuracy of formation of such a structure.

The technique of formation of a miniaturized interconnection pattern involves the layering as shown in Fig. 7A having interconnect layer 46 and oxide film 48. Oxide film 48 is dry etched while the resist film 50 is used as a mask. Resist film 50 is removed, and then oxide film 48 is reduced by means of wet etching, as shown in Fig. 7C. The reduced oxide film 48 is then used as a mask while interconnection layer 46 is dry-etched, resulting in the structure shown in Fig. 7D (Specification, p. 16, ll. 10-29).

Appellant states that the reasons for dimensional errors in making the above structure occur from (1) dimensional errors in the resist film 50 formed by photolithography and (2) dimensional errors in the oxide film 48 caused by side etching, which etching would arise during the dry etching process (Specification p. 16, ll. 30 – p. 17, ll. 1-2).

Appellant states that, therefore, in the fifth embodiment, in order to accurately set the final dimensions of the interconnection 52 to a desired value, dimensional errors in the resist film 50 and those in the oxide film 48 are corrected by means of the feed forward technique. Specifically, the resist film 50 is formed by photolithography, then the oxide film 48 is *dry-etched*, and then *the resist film 50 is removed*. Then, the dimension of the patterned oxide film 48 is measured.[1] The measured value is reflected in the requirements for *wet-etching* the oxide film 48 by means of the feed forward technique (Specification, p. 17, ll. 7-19).

As made evident from the above-described parts of Appellant's specification, Appellant uses the feed-forward technique to improve upon techniques used in semiconductor processing (e.g., techniques such as step formation, as in embodiment 1, or formation a miniaturized interconnection pattern, as in embodiment 5). In other words, by measuring the dimension of a film between a step in a process, and using the measured values for setting the optimal requirements of the etching machine, the film is processed according to the optimal requirements. The critical aspect, therefore, of Appellants' claim 6 is the use of the feed forward technique in the formation of a semiconductor structure. The type of processing steps is not indicated as critical. That is, the feed forward technique is used by Appellant in-between a variety of steps (e.g., CMP, measuring, followed by etching (embodiment 1) or etching, removal of resist, measuring, followed by etching (embodiment 5)).

1The description of this embodiment actually indicates that an additional step (resist removal) is also conducted after the dry etch step and before the wet etch step.

Both Appellant and our dissenting colleague views the types of etching steps that are conducted before and after a measurement is taken as an unobvious feature of the claimed invention. We do not agree, for the following reasons.

The use of etching for active area definition, gate recess etching, and waveguide formation is well recognized by persons of ordinary skill in the art in the field of compound semiconductor processing. *Kirk Othmer, Encyclopedia of Chemical Technology,* vol. 21 (4th ed., 1997) p. 798. According to the reference, wet etching can provide a clean, damage-free surface with good control of both etch depth and lateral undercut. *Id.* The reference discloses one advantage of wet etching over dry etching is the absence of subsurface damage that is common with dry etching. Metal contacts placed on wet-etched surfaces exhibit more ideal characteristics than dry-etched surfaces. *Kirk,* p. 800. The reference further discloses that for certain applications dry etching has gained popularity over wet etching because of its increased control of etch profiles, attaining submicrometer features and the ability to introduce in situ monitoring capabilities into a dry-etch system. *Id.* Most wet etches are isotropic which may limit their usefulness in high aspect ratio submicrometer applications where straight wall profiles are required.

We reiterate that Appellant admits the following steps have been known in the art: (1) etching step, (2) dimension of the film acquired, and (3) etching step. That is, as discussed, *supra*, Appellant's admitted prior art on page 1 of the specification involves an etch step (type not specified), followed by measuring the thickness of the film, followed by another etch step (type not specified). A feed back technique is used rather than a feed forward technique.

Funk teaches use of the feed forward technique. As admitted by Appellant on page 7 of the Brief, Funk teaches a feed forward control mechanism with regard to the manufacture of semiconductor devices (obtaining a variable after a first process to modify the operation of a second process). See, e.g., column 5 of Funk beginning at line 22 through column 6, line 22. In this disclosure, Funk teaches the use of the feed forward technique (wafers are tested for collecting data to be used in determining processing steps of the wafer). Funk teaches the use of feed forward control to enable feed forward control to areas of manufacturing (Funk, col. 3, ll. 27-30). As a specific example, Funk teaches an etching material result that includes FICD and the resulting FICD parameter is fed forward for further processing (Funk, col. 10, ll. 58-61).

Appellant argues that Funk does not specifically teach the specific set of processing steps of dry etching and wet etching and in a specific order (i.e., wet etching after dry etching). However, as explained by the Examiner on pages 3-4 of the Answer, Funk teaches that material may be etched using different etch processes, such as wet etch and plasma etch (dry etch). See column 11, lines 12 through 15 of Funk. The Examiner points out that Funk teaches that the process control system according to Funk performs a process including a plurality of process steps that are performed in a sequence. See column 2, lines 38 through 40 of Funk. Funk also teachings that multiple chambers are utilized in conducting a set of processing steps. See column 11, lines 15-16 lines 33-53. Funk teaches that the material may be etched in multiple etching chambers (Funk, col. 11, lines 13-15, and 21-53).

Our dissenting colleague believes that such teachings would not have suggested to one of ordinary skill in the art to perform a dry etching step followed by a wet etching step. We disagree. The fact that Funk does not attach an importance to the order of the

types of etching steps is in effect a teaching that a particular order can be selected based upon process/product requirements. Hence, we agree with the Examiner's position wherein the Examiner concluded that Funk suggests to one of ordinary skill in the art that dry etching and wet etching can be conducted, and that the specific order of such etching will be chosen according to the specific requirements. Absent evidence of criticality[2], as in the instant case, we agree with the examiner that a *prima facie* case of obviousness has been established in this regard.

With regard to Appellant's argument that Funk does not suggest the specific variable (i.e., dimension of the film) that is to be acquired, we again agree with the Examiner's explanation. The Examiner, on page 3 of the Answer, explains that Funk utilizes FICD (Final Inspect Critical Dimension measurement). Funk defines FICD measurements as being relevant for analyzing two aspects of feature sizes. One aspect is a critical dimension, the absolute size of a feature, including line width, spacing or contact dimension. Funk also teaches that another aspect is the variation in feature size across the wafer surface as measured by steps of a wafer stepper. See column 11, lines 54-62 of Funk.

We therefore agree with the Examiner that Funk's measurement of dimensions suggests measurement of the dimension of a film.

We also, again, note that Appellant admits on page 1 of the specification, that the thickness of a film is a common measurement taken between etching steps in an effort

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2 Our dissenting colleague views Appellant's specification, regarding embodiment 5, as describing an advantage of performing a wet etch after a dry etch. We believe that an "advantage" is not evidence of unexpectedly superior results which is required to rebut a *prima facie* case.

to stabilize processing (the admitted prior art uses the measurement taken in a feed back technique). Funk teaches the advantages of using a feed forward technique and both kinds of etching techniques (no specific order required). It would therefore have been obvious to have utilized a feed forward technique when conducting a dry etching step followed by a wet etching step in view of the aforementioned teachings, to achieve the advantages taught in Funk of using a feed forward technique.

In view of the above, we affirm the 35 U.S.C § 103(a) rejection of claim 6.

II. Conclusion

The 35 U.S.C. § 103 rejection of claim 6 as being obvious over Funk is affirmed.

No time period for taking any subsequent action in connection with this appeal may be extended under 37 CFR § 1.136(a).

<u>AFFIRMED</u>

ADAMS, *Administrative Patent Judge*, dissenting.

The only claim before this panel for review is directed to a method for the manufacture of a semiconductor device. *See supra*, claim 6.[3] As I understand claim 6 the method comprises the following two etching steps:

(1) dry etching a predetermined film to be processed; and

(2) wet etching, *after said step of dry etching*, the predetermined film to be processed.

To further emphasize the order of these etching steps, claim 6 also requires that the wet etching step be performed in accordance with the following two processing requirements, which occur after the dry etching step:

(a) acquiring, *after said step of dry etching*, the dimension of the film to be processed; and

(b) determining processing requirements for said step of wet etching on the basis of the dimension of the film to be processed.

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[3] The only remaining pending claims, claims 4, 5 and 7-19 have been withdrawn from consideration pursuant to the provisions of 37 C.F.R. § 1.142(b). Specifically, claims 11-19 were withdrawn from consideration in response to the December 18, 2002 restriction requirement. *See* Appellant's election, received January 16, 2003, wherein the subject matter of then pending claims 1-10 was elected for prosecution on the merits. Appellant subsequently cancelled claims 1-3. *See* amendment received May 13, 2003. Claims 4, 5 and 7-10 were then withdrawn from consideration in response to the June 5, 2003 requirement to elect a single disclosed species for prosecution on the merits. *See* Appellant's election, received June 26, 2003.

Therefore, there can be no doubts that claim 6 requires that the wet etching step is performed after the dry etching step. For clarity, claim 6 is drawn to a method that comprises the following steps in the order recited:

(i) dry etch a predetermined film to be processed;

(ii) acquire the dimension of the film to be processed after step (i);

(iii) determine the processing requirements for the wet etching step based on the dimension of the film acquired in step (ii); and

(iv) wet etch the predetermined film to be processed according to the processing requirements determined in step (iii).

Thus, the literal language of the claim supports the construction of claim 6 as comprising the steps in the order recited. Appellant's specification also supports this construction of the claimed method. According to Appellant's specification (page 19), "[i]n the manufacturing system according to the present embodiment, wet-etching requirements can be corrected on the basis of the dimension of the oxide film . . . which has been dry-etched." More specifically, Appellant discloses as a fifth embodiment of the invention, the advantage of performing the process steps in the order recited in claim 6. *See* Specification, pages 16-17 and figures 7A-7E, wherein Appellant discloses:

> The principal reasons for causing dimensional errors in the interconnection 52 formed through the foregoing procedures are (1) dimensional errors in the resist film 50 formed by means of photolithography and (2) dimensional errors in the oxide film 48 caused by side etching, which etching would arise during the dry etching process. In

> the present embodiment, in order to accurately set the final dimension of the interconnection 52 to a desired value, dimensional errors in the resist film 50 and those in the oxide film 48 are corrected by means of the technique to be described below.
>
> As shown in Fig. 7E, in the present embodiment, the resist film 50 is formed through use of photolithography at first. Then, the oxide film 48 is dry-etched using the resist film 50 as a mask. After removing the resist film 50, the dimension of the patterned oxide film 48 is measured. The resultantly-measured value is reflected in the requirements for wet-etching the oxide film 48 by means of the feed forward technique.

In my opinion, it would seem quite clear that Appellant's specification supports the construction of claim 6 as comprising the steps in the order recited. In addition, as the majority recognizes (*supra*, page 5),

> Appellant states that the reasons for dimensional errors in making the . . . [structure set forth in embodiment 5] occur from (1) dimensional errors in the resist film 50 formed by photolithography and (2) dimensional errors in the oxide film 48 caused by side etching, which etching would arise during the dry etching process (Specification p. 16, ll. 30 – p. 17, ll. 1-2).

Therefore, as I understand it, the majority recognizes (*supra*, pages 5-6) that embodiment 5 of Appellant's specification "supports the subject matter of claim 6," and provides an advantage of performing a wet etching step after a dry etching step. Therefore, Appellant's specification supports the construction of claim 6 requiring that the wet etching step is performed after the dry etching step. The analysis does not end there, as the prosecution history of this application also supports this construction of claim 6.

Originally presented claim 6 did not include the process steps set forth in claim 6 now before us on appeal. During prosecution the examiner rejected the originally presented claim under 35 U.S.C. §§ 102(b), and 102(e). *See* Office Action, mailed February 20, 2003. In response, Appellant amended claim 6 to add specific process steps including the requirement that the wet etching step is performed after the dry etching step. *See* page 4, Paper received May 13, 2003. In addition, Appellant argued that the prior art did not teach the order of the process limitations as set forth in the amended claim. *Id.*, pages 9 and 10. The examiner responded by withdrawing the rejections of record and issuing the rejection over Funk that is now before us on appeal. *See* Office Action, mailed July 15, 2003, pages 2 and 3.

In all, it would appear that not only the plain meaning of the claim language, but the specification and the prosecution history support the construction of Appellant's claim 6 as drawn to a process that comprises steps which are performed in the order set forth in the claim, including the requirement that the wet etching step is performed after the dry etching step. *Loral Fairchild Corp. v. Sony Corp.*, 181 F.3d 1313, 1322, 50 USPQ2d 1865, 1870 (Fed. Cir. 1999) ("Although not every process claim is limited to the performance of its steps in the order written, the language of the claim, the specification and the prosecution history support a limiting construction in this case.").

As the majority recognizes (*supra* page 3), Appellant focuses on this particular ordering of the process steps to distinguish claim 6 from the Funk reference asserting,

inter alia, that Funk fails to teach that "wet etching takes place after dry etching." *See e.g.*, Brief, page 5. In addition, the majority recognizes (*supra*, page 5), Appellant's assertion

> that the Examiner has failed to establish a realistic motivation to modify Funk so as to arrive at the claimed limitation of performing wet etching after dry etching. Appellant argues that the Examiner's assertion that "it would have been obvious to one with ordinary skill in the art to perform various processes in various sequences depending on the specific product requirement" is overly broad and based on generalities.

In this regard, I note that conclusions of obviousness must be based upon facts, not generality. *In re Warner*, 379 F.2d 1011, 1017, 154 USPQ 173, 178 (CCPA 1967), *cert. denied*, 389 U.S. 1057 (1968); *In re Freed*, 425 F.2d 785, 788, 165 USPQ 570, 571 (CCPA 1970).

The majority recognizes that Funk does not teach a dry etching step followed by a wet etching step, as is required by Appellant's claimed invention. *Supra* page 8. The majority finds, however, "[t]he fact that Funk does not attach an importance to the order of the types of etching steps is in effect a teaching that a particular order can be selected based upon process/product requirements." *Supra, bridging paragraph, pages 8-9.* Therefore, the majority finds that a *prima facie* case of obviousness has been established because "Funk suggests to one of ordinary skill in the art that dry etching and wet etching can be conducted, and that the specific order of such etching will be chosen according to the specific requirements." *Supra* page 9. What "specific requirements" would be necessary to lead a person of ordinary skill in the art to Appellant's claimed invention, the examiner, the majority and Funk do not say. In this regard, I remind the majority that "selective hindsight is no more applicable to the

design of experiments than it is to the combination of prior art teachings." *In re Dow Chem. Co.*, 837 F.2d 469, 473, 5 USPQ2d 1529, 1531 (Fed. Cir. 1988).

There must be a reason or suggestion in the art for selecting the procedure used, other than the knowledge learned from the applicant's disclosure. *Interconnect Planning Corporation v. Feil,* 774 F.2d 1132, 1143, 227 USPQ 543, 551 (Fed. Cir. 1985). Stated differently, while a person of ordinary skill in the art may possess the requisite knowledge and ability to modify the protocol taught by Funk, the modification is not obvious unless the prior art suggested the desirability of the modification. *In re Gordon,* 733 F.2d 900, 902, 211 USPQ 1125, 1127 (Fed. Cir. 1984). In my opinion, the record presented for our review provides no suggestion to modify Funk in a manner that would lead to Appellant's claimed invention. In my opinion, the only suggestion on this record to arrange the process steps as set forth in Appellant's claimed invention comes from Appellant's specification, but "[t]o imbue one of ordinary skill in the art with knowledge of the invention in suit, when no prior art reference or references of record convey or suggest that knowledge, is to fall victim to the insidious effect of a hindsight syndrome wherein that which only the inventor taught is used against its teacher." *W.L. Gore & Associates, Inc. v. Garlock, Inc.*, 721 F.2d 1540, 1553, 220 USPQ 303, 312-13 (Fed. Cir. 1983).

Because Funk does not provide the requisite suggestion to arrange the process steps in the manner necessary to arrive at Appellant's claimed invention the examiner failed to meet his burden[4] of establishing a *prima facie* case of obviousness.[5] If the examiner fails to establish a *prima facie* case, the rejection is improper and will be overturned. *In re Fine*, 837 F.2d 1071, 1074, 5 USPQ2d 1596, 1598 (Fed. Cir. 1988). For the foregoing reasons, it is my opinion that the rejection of claim 6 under 35 U.S.C. § 103 over Funk is in error and should be reversed.

Apparently recognizing that the rejection of record cannot be sustained the majority reaches outside of the record presented for our review to prop up the examiner's rejection with two new pieces of evidence. The majority relies on the *Kirk Othmer, Encyclopedia of Chemical Technology* (Encyclopedia), to teach that wet etching and dry etching are known to those of ordinary skill in the art and that "one advantage of wet etching over dry etching is the absence of subsurface damage that is common with dry etching." *Supra* page 7. As I understand the record before us for review, I do not believe there is any dispute that wet etching and dry etching were

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[4] "In rejecting claims under 35 U.S.C. § 103, the examiner bears the initial burden of presenting a *prima facie* case of obviousness." *In re Rijckaert*, 9 F.3d 1531, 1532, 28 USPQ2d 1955, 1956 (Fed. Cir. 1993).

[5] I recognize the majority's assertion that "an 'advantage' is not evidence of unexpectedly superior results which is required to rebut a *prima facie* case." *Supra* page 9, n. 2. In my opinion, this assertion puts the cart before the horse. Secondary considerations of non-obviousness are not at issue until the examiner first makes out a *prima facie* case of obviousness. Since the examiner has not provided the evidence necessary to establish a *prima facie* case of obviousness we need not look to any secondary considerations of non-obviousness.

known in the art prior to the date of Appellant's claimed invention. Instead, the dispute on this record is whether the prior art of record teaches the method set forth in Appellant's claim 6. Further, while the majority highlights a number of statements in the Encyclopedia, the rationale for citing these statements is less than clear. *See id.* While the majority has not clearly expressed it on this record, it may be that the majority is of the opinion that the combination of Funk with the Encyclopedia would render Appellant's claimed invention *prima facie* obvious to a person of ordinary skill in the art at the time the invention was made. If this is so, it would appear that any such rejection over the combination of Funk with the Encyclopedia would be a new ground of rejection under 37 C.F.R. § 41.50(b). The majority, however, did not find their reliance on the Encyclopedia raises to the level of a new ground of rejection, therefore, the procedural due process provided for in 37 C.F.R. § 41.50(b) is not available to Appellant. In my opinion, if the majority intends to rely on the Encyclopedia in combination with Funk the majority should clearly state this intent on the record and provide Appellant with the opportunity to respond as provided by 37 C.F.R. § 41.50(b).

The majority also points to page 1 of Appellant's specification suggesting that Appellant admits that a method was known in the art wherein an unspecified etching step was performed, followed by the step of acquiring the dimension of the film, and then another unspecified etching step. *Supra* page 7. The majority also notes that Appellant's specification suggests that as part of this "known" method "a feed back technique is used rather than a feed forward technique." *Id.* Other than suggesting (*supra* page 9) "that the thickness of a film is a common measurement taken between etching steps", the majority fails to explain how these uncharacterized etching steps

together with a feed-back technique would lead a person of ordinary skill in the art to Appellant's claimed invention either alone or in combination with Funk, when none of this evidence suggests that a dry etching step be performed prior to a wet etching step as is required by Appellant's claimed invention. "[R]ejections on obviousness grounds cannot be sustained by mere conclusory statements; instead, there must be some articulated reasoning with some rational underpinning to support the legal conclusion of obviousness." *In re Kahn*, 441 F.3d 977, 988, 78 USPQ2d 1329, 1336 (Fed. Cir. 2006), citations omitted.

For the foregoing reasons I disagree with the majority opinion. Therefore, I dissent.

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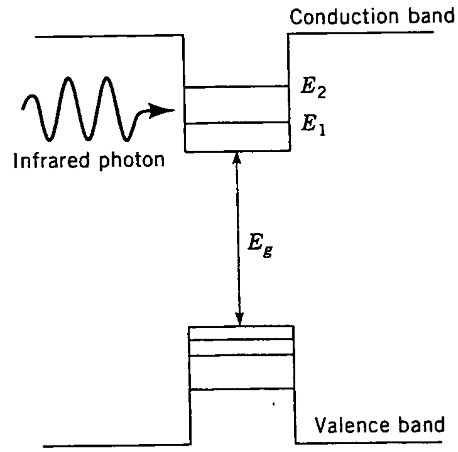

Fig. 13. Absorption between confined energy levels in a quantum well infrared photodetector (QWIP). The energy difference (E_2-E_1) between the confined energy levels in a quantum well may be designed such that it is resonant with ir radiation. The band gap, E_g, is much greater, therefore direct band gap absorption does not occur.

19 μm (127). Although HgCdTe-based detectors still have higher detectivities at longer wavelengths ($\lambda > 8$ μm) and at operating temperatures in the 4–77 K region, the GaAs-based QWIPs show higher detectivity at temperatures below 40 K (128).

Many of these material systems have been developed into avalanche photodiodes (APDs) which involve not only the generation of carriers with the absorption of light but also the amplification of the generated carriers (75,76). This is accomplished by applying a very high reverse bias to the detector, resulting in a high enough internal electric field inside the material to generate additional carriers by impact ionization. These detectors therefore have a higher responsivity than more conventional photodiodes, but suffer from increased noise.

As for LEDs, substantial improvement in detector performance can be achieved by placing the LED structure inside a resonant cavity. In particular, the resonant cavity photodetector can achieve high quantum efficiencies in a relatively narrow spectral region (86). In one study, a mirror was designed to allow for resonant absorption of two wavelengths: 730 and 910 nm (129). This type of multiple wavelength detector shows promise for wavelength division multiplexing (WDM) systems where wavelength multiplexing enables enhanced transmission capacity.

Device Fabrication Technology

WET ETCHING

Compound semiconductor processing makes extensive use of etching for, eg, active area definition, gate recess etching, and waveguide formation. Wet etching can provide a clean, damage-free surface with good control of both etch depth and lateral undercut. Most wet etches are isotropic which may limit their usefulness

in high aspect ratio submicrometer applications where straight wall profiles are required. With the proper combination of semiconductors and etchants, excellent selectivity can be achieved to extend the utility of wet etches to the nanometer range.

Etch Profiles. The final profile of a wet etch can be strongly influenced by the crystalline orientation of the semiconductor sample. Many wet etches have different etch rates for various exposed crystal planes. In contrast, several etches are available for specific materials which show little dependence on the crystal plane, resulting in a nearly perfect isotropic profile. The different profiles that can be achieved in GaAs etching, as well as InP-based materials, have been discussed (130–132). Similar behavior can be expected for other crystalline semiconductors. It can be important to control the etch profile if a subsequent metallization step has to pass over the etched step. For reliable metal step coverage it is desirable to have a sloped etched step or at worst a vertical profile. If the profile is re-entrant (concave) then it is possible to have a break in the metal film, causing an open defect.

A powerful feature of wet etching is the ability to achieve excellent etch selectivities of one material over another. This can be extremely useful in the fabrication of epitaxial devices with different material layers. Because selective etching allows the removal of specific layers, the final accuracy of the etch can approach that of the epitaxial layers. Etch selectivities of >100:1 have been achieved for citric acid:H_2O_2 etching of GaAs–AlGaAs and InGaAs–InP structures (133).

Table 4. Wet Etches for Compound Semiconductors

Semiconductor	Etch	Typical rates, μm/min	Reference
GaAs	H_3PO_4:H_2O_2:H_2O	0.01–4.0	137
[a]	$C_6H_8O_7$:H_2O_2	0–0.3	133
[b]	H_2SO_4:H_2O_2:H_2O	3–14	137,138
[c]	NH_4OH:H_2O_2	0.1	139
AlGaAs	$C_6H_8O_7$:H_2O_2	0–0.2	133
InGaAs	$C_6H_8O_7$:H_2O_2	0–0.14	133
InP	HCl	6	140
	HCl:H_3PO_4	0.1–1.0	141
	Br–CH_3OH	0.4	140
InAs	$C_6H_8O_7$:H_2O_2	0.09	142
InSb	I_2:CH_3OH		143
GaSb	HNO_3:HF:CH_3COOH		143
[d]	$C_6H_8O_7$:H_2O_2	0.9	142
CdTe	Br:CH_2OHCH_2OH	0.08	144
ZnTe	HNO_3:HF		143
ZnS	$K_2Cr_2O_7$:H_2SO_4		143
AlN[e]	photoresist developer	0.01–1	145
GaN[d]	NaOH–H_2O	2	146
InN[d]	HCl–HNO_3	1	146

[a]GaAs selective to AlGaAs. [b]GaAs at 300 K. [c]GaAs agitated. [d]Rate = nm/min. [e]Active component is KOH.

Etch Mechanisms. Most wet etches for the compound semiconductors employ oxidation of the semiconductor followed by dissolution of the oxide. For this reason, many wet etches contain the oxidant hydrogen peroxide, although nitric acid can also be used. One advantage of wet etching over dry is the absence of subsurface damage that is common with dry etching. Metal contacts placed on wet-etched surfaces exhibit more ideal characteristics than dry-etched surfaces.

Etch Chemistries for Compound Semiconductors. There is a great diversity in the number of wet etches used for compound semiconductors. By choosing the correct etch the result can be highly selective or completely nonselective, etching through multiple epitaxial layers with nearly constant rates. The profile can be isotropic or depend on the crystal orientation. Most photoresists do a fairly good job of withstanding the wet etches. However, if a dielectric or metal surface is to be exposed during the etch it is important to consider parasitic etching of these materials (134). The large number of etchants available for compound semiconductors is extensive and therefore only a limited number of them are listed in Table 4. Several references for the wet etching of GaAs and InP are available (135,136).

DRY ETCHING

For certain applications dry etching has gained popularity over wet etching because of its increased control of etch profiles, attaining submicrometer features and the ability to introduce *in situ* monitoring capabilities into a dry-etch system. In general, dry etching of III–V semiconductors involves exposing the semiconductor to a directed energetic reactive plasma, which etches the semiconductor through a combination of physical and chemical processes. Different etch systems and/or conditions can be used to vary the amount of physical or chemical etching. Ion-beam milling involves the purely physical sputtering action of argon atoms, while reactive ion etching (RIE) can have a very strong chemical component with highly isotropic profiles.

Dry-Etching Systems. The fundamental operational characteristic of a dry-etch system is the exposure of a semiconductor sample to energetic reactive gases. The gases that are introduced into the etch system have a large impact as to whether the etch has any chemical component or is a purely physical etch, as in ion milling. The pressures used are generally <13.3 Pa (0.1 mm Hg) in order to reduce gas-phase interactions, increase the mean free path of the energetic gases, and control lateral etching. Very anisotropic etching usually occurs with pressures <1.33 Pa and d-c biases >100 V. A plasma is generated in the etchant gases by several techniques, including radio-frequency (r-f) energy, microwave energy, and microwave energy combined with magnetic confinement. The plasma may be located remote from the sample or the sample may be directly within the plasma.

Ion-beam milling is a dry-etch process that is 100% physical, using argon plasmas in a highly energetic mode of operation. Chemically assisted ion-beam etching (CAIBE), reactive ion-beam etching (RIBE), and electron cyclotron resonance (ECR) etching are similar in that the plasmas are located remotely from the semiconductor. Systems that remove the sample from the plasma in a down-

stream mode allow excellent independent control of the physical and chemical components of the etch. Inductively coupled plasma (ICP) etching and reactive ion etching have the sample sitting directly in the plasma. However, ICP etching allows decoupling of the ion density and ion energy, resulting in excellent control over the etch characteristics.

The physical component of the etch can cause damage to the semiconductor surface (147). Although this damage can often be annealed out at low temperatures, this is not always possible in the fabrication sequence. Additionally, in some cases it is necessary to use a wet etch to remove a thin damaged layer formed during a dry etch. If the etch is designed to have a chemical component then the atomic species in the plasma interacts with the semiconductor forming volatile by-products which desorb from the surface. The sample stage can often be heated or cooled to control the volatility of these by-products. Etches with strong chemical components are more isotropic, but introduce less damage to the semiconductor surface.

As with any other fabrication process, masks are needed to define the features to be etched. It is common that the etch used for the semiconductor also etches the masking material. For this reason many different masks are used in etching, including photoresist, dielectric films, and metals. Masking can be a complex issue, especially when very deep etches (>5 μm) are performed with high aspect ratios (148).

Gases for Etching. The primary factor in choosing a gas for dry etching of compound semiconductors is its ability to form volatile compounds with the semiconductor's constituent atoms. These volatile compounds are either thermally desorbed from the surface or desorb through an ion-assisted process (149). All gases used have a physical component associated with its ability to sputter the semiconductor surface. A wide variety of gases have been used in the etching of compound semiconductors and listing them all is beyond the scope of this article. A short listing of gases for various semiconductors is shown in Table 5 (150,151).

ION IMPLANTATION

Although a great number of compound semiconductor devices make use of epitaxy to form the core vertical structure of the device, ion implantation (qv) is a powerful tool in creating both horizontal and vertical modifications to a device. Ion implantation can be used to dope a semiconductor either *n*- or *p*-type by using appropriate species. Implantation can also be used to render a region semi-insulating or to initiate multilayer intermixing.

Ion Implantation Systems. An ion implantation system is used to accelerate ionized atomic or molecular species toward a target sample. The ionized species penetrates the surface of the sample with the resulting depth profile dependent on the implanted species mass, energy, and the sample target's tilt and rotation. An implanter's main components include an ionizer, mass separator, acceleration region, scanning system, and sample holder (168).

The implanted ion can be singly or multiply charged and can be any isotope. The mass separation system is used to avoid contamination. As an example, when implanting silicon the $^{29}Si^{+}$ isotope is often used instead of $^{28}Si^{+}$ to avoid